PLANTAR PRESSURE ANALYSIS DURING STAIR DESCENT WITH VARIOUS LOADS IN CHILDREN

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Thirteen school children aged 12.21 ± 0.98 years carried backpack and one-strap athletic bag during their stair ascent and descent. The load weights of the bags included 0%, 10%, 15%, and 20% of body weight. A Novel Pedar System was used to record and analyze the insole pressure during stair descending with different loads. The first peak force was 1.59 times the second peak force. A load of 15% of body weight induced a significant increase in the maximum peak force for both bags, which was 195% of body weight and 1.25 times the peak force with no load. The force-to-time ratio of the first peak force in this stair mode was about 3 times that in the stair ascent presented in the previous study.

KEY WORDS: stair walking, load carriage, plantar pressure, children.

INTRODUCTION: Both load carriage and stair walking are frequently encountered during the course of normal daily activities. In many schools, children need to carry their schoolbags up and down stairs. The problem of over-weight schoolbags has been of high concern to parents and the community in recent years. The movement kinematics and kinetics of adult's stair walking have been extensively studied (Adrian, Moustafa, Duck et al. 1989; McFadyen and Winter 1988; Loy and Voloshin 1991; Zachazewski and Riley 1993; Riener, Rabuffetti, Frigo 2002). However, to author's knowledge, little is known about the influence of carrying weight and methods on gait kinematics and ground reaction force of children during stair walking. Stair descent has been proved to produce greater ground peak force than stair ascent (Loy and Voloshin 1991; Riener, Rabuffetti, Frigo 2002). Hence, the purpose of this study was to investigate the effects of load and carrying methods on ground reaction force and gait temporal characteristics during stair descent in children. The results of this study will enrich our understanding of the possible hazards that are induced by children carrying heavy schoolbags during daily stair walking.

METHODS: Thirteen male students aged 12.21 ± 0.98 years (body weight 47.12 ± 9.69 kg, body height 159.66 ± 9.67 cm) were recruited from a secondary school to serve as subjects. All of the subjects were free of injury during the test and did not have injury histories that had caused abnormal gaits or an inability to climb stairs. A consent form was signed and body weight and body height were recorded before the test.

The carrying methods compared in this study were carrying a one strap athletic bag (across the right shoulder, the dominant side of all subjects) and a backpack (on both shoulders), which represented asymmetrical and symmetrical load carrying methods, respectively. Four loads, at 0, 10, 15, and 20% of the subjects' body weight, were used. Before stair walking, the subjects rested for 5 minutes. They were then asked to walk on level ground with a load of 20% of body weight for 400m in free speed to simulate a normal walk to school from home. After the floor walking, the stair walking trial began. In each trial, the subjects climbed the 33-step staircase, then turned around and walked down to the starting point by following the same path. This process was performed three times. To reduce the risk of accumulative fatigue affecting performance, the subjects were asked to take a rest after each trial. For each trial, three complete gait cycles from the 21st to the 15th step of the stair in each descent were selected for analysis, leading to 9 complete gait cycles of stair descent.

A 4×2 (loads × bags) factorial design, i.e. altogether eight separated combinations (trials), was used. The order of sessions for the 8 trials was randomized using a Latin square design. The place of the test was the audience seating of the university's gymnasium. The step dimensions were 16 cm (riser) by 35 cm (tread) with the slope being 25.2°, which is within the recommended stair slope and dimensions of stair riser and tread (Templer 1997).

An in-shoe pressure measurement system (Novel Pedar System, Germany) was employed to record the temporal and kinetic data during stair walking. Each Novel Pedar insole contained 99 force sensors. With the aid of the trublu calibration device (Novel Pedar System, Germany), all sensors of the insole were individually calibrated before testing each day. The insoles were placed inside both of each subject's shoes to record the vertical reaction forces of each sensor during contact against time. The data collection box was attached to a waistband during the stair walking. Data were collected with the Novel Pedar System at 50 Hz. The force signals of sensors were recorded and saved in a PCMCIA card that was installed in the collection box of the system for each trial. Each subject used the same brand of shoes that are most widely worn by the local school students.

The dependent variables included the peak vertical ground reaction forces, force-to-time ratio of the first peak force, the gait cycle duration, stance duration, single and double support duration, and time to peak force. Only the first peak force was calculated for the force-to-time ratio because, as discussed in a previous study of stair walking by adults without loads (McFadyen, Winter 1988; Zachazewski, Riley 1993) only this peak force showed an impulsive nature due to its short development time. In each trial, the dependent variables were averaged across the 9 complete gait cycles to represent the biomechanical features for each bag and load combination.

Two-way analysis of variance (ANOVA) with repeated measures was used. The analysis examined the extent of interaction between the two bags and four loads. Providing the main effect on the load was significant, by fixing the type of bag, a one-way ANOVA Post-Hoc multiple comparison, the LSD test, was conducted to determine whether any of the four loads were significantly different from the others in the variable concerned. If the two-way ANOVA showed significance for the main effect on the bag, then by fixing the load, a paired T test was conducted to ascertain whether there was a significant difference between the bags in the variable concerned. The significance levels for all tests were set at 0.05.

RESULTS: In the case of backpack carrying, statistical analysis showed that there was no significant difference between the right and left foot in each dependent variable. This allowed an averaging of the dependent variables for the two feet. With athletic bag carrying, the peak force of the left foot was found to be greater than that of the right foot. Hence, the dependent variables of the left foot were chosen for analysis.

The continuous recordings of the bilateral insole forces demonstrated the bimodal pattern of the ground reaction force for each foot, further confirming previous reports. In this paper, the gait cycle begins with the initial landing of the leading foot, and ends with the next landing of the same foot. Based on bilateral foot movements, a complete gait cycle contains: 1. the first double stance; 2. the first single support phase; 3. the second double support phase; and 4. the second single support phase. For the leading leg, the complete gait cycle is composed of one stance followed by one swing phase. The stance phase, in turn, involves the first double support, the first single support and the second double support phases. The temporal and kinetic parameters were presented in Table 1 and Table 2 respectively.

Table 1 Temporal parameters in stair descent (Gait cycle duration in s; other variables in % of gait cycle duration).

	Backpack load				Athletic bag load			
	0%	10%	15%	20%	0%	10%	15%	20%
Gait cycle duration	1.15	1.17	1.11	1.20[ac]	1.05	1.07	1.10	1.22[abc]
Double support duration	19.23	19.05	20.72[a]	20.76[a]	18.76	19.63	19.97	20.75
Time to contralateral takeoff	9.62	9.53	10.36[a]	10.38[a]	9.38	9.81	9.99	10.37
Time to contralateral touch down	49.73	51.11	50.05	50.13	49.96	49.79	50.03	50.30
Time to lead leg takeoff	59.46	59.15	59.62	58.85	58.75	59.57	59.65	60.32
Time to 1st peak force	11.00	11.25	11.88	11.61	12.44	12.30	12.85	12.84
Time to 2nd peal force	51.82	51.73	49.92	48.09[ab]	51.56	51.47	49.67	47.85[ab]

A: other loads vs. 0%, $p<0.05$; b: 15% and 20% vs. 10%, $p<0.05$; c: 20% vs. 15%, $p<0.05$

Table 2 Plantar force in stair descent (all forces in % body weight; force-to-time ratio in Newton/s).

	Backpack load				Athletic bag load			
	0%	10%	15%	20%	0%	10%	15%	20%
Lead leg 1st peak force	155.74	165.34	195.09^{ab}	191.83^{ab}	166.51	181.10	195.43^{a}	181.42^{a}
Contralateral force 1	11.87	16.02	16.80	14.61	12.65	11.73	14.24	13.20
Lead leg 2nd peak force	89.58	93.39	93.58	95.4^{a}	93.20	91.90	96.52^{b}	100.38^{b}
Contralateral force 2	8.64	6.93	12.67	9.81	8.23	9.11	11.48	10.11
Force-to-time ratio	6280.54	6275.73	6960.29	6751.42	6270.23	6685.47	6998.70	6456.62

Contralateral force 1 = contralateral force at the moment the lead leg 1st peak force occurs.
Contralateral force 2= contralateral force at the moment the lead leg 2nd peak force occurs.
a: other loads vs. 0%, $p<0.05$; b: 15% and 20% vs. 10%, $p<0.05$; c: 20% vs. 15%, $p<0.05$; †: backpack vs. athletic bag, $p<0.05$.

DISCUSSION: Table 2 shows that a load of 20% of body weight induced a significant increase in gait cycle duration compared with no load. Research found that when subjects carried different loads and walked with self-selected speed on the ground, with an increase of load the walking speed and stride length decreased while the cadence increased with respect to an unloaded condition (Kinoshita 1985; Nottrodt, Manley 1989). Typically, when free speed is permitted, subjects tend to minimize the effect of load on their energy cost by decreasing walking velocity. However, due to the physical constraint imposed by the fixed dimensions of the stairs, lengthening the gait cycle duration directly contributes to the reduction of propagation velocity. The data suggests that a load of 20% of body weight caused higher biomechanical stain, thus forcing the subjects to change their velocity.

As seen in Table 3, stair descent showed significantly greater first peak force than the second for both bags. As the carrying load increased from 0% to 15% of body weight, the first peak force increased from 155.74% to 195.09% of body weight. This partly confirmed the findings of Adrian et al. (1989), who reported 1.5 times body weight for the peak vertical force during normal stair descent, almost 2 times body weight for the maximum peak force during fast descent, and approximately body weight during slow descent. The results indicated that the maximum peak force changes with walking speed and load condition.

Loy and Voloshin (2002) showed that normal stair descent induced shock waves with an amplitude of 1.3 times that observed in stair ascent and 2.5 times that experienced in level gait. Riener et al. (1993) reported considerably higher ground reaction forces during descent than during ascent in the normal condition, i.e. walking without carrying load. When the load increased, the total weight of the locomotor system increased, which lead to an increase in shock waves. The present study agrees the previous claims by adding quantitative information obtained from the load carrying condition. Table 3 shows that in stair descent, a load of 15% of body weight was critical and significantly increased the first peak force with both bags. The maximum peak force induced by this load was 1.25 times that measured in the no load condition. Lieber (1992) indicated that to sustain the shock wave that is encountered in stair descent, the antigravity muscles perform eccentric contractions, i.e. they generate force while they are lengthened. These situations are related to the potential risk of muscle fiber damage when the speed or load becomes too great. Obviously, the higher impulsive cyclic loads that are generated by stair descent with a load of 15% of body weight or above place the neuromuscular system, especially the knee joint, at risk, and contribute to the progression of the degenerative process of the natural shock absorbers of the musculoskeletal system in children. The continuous and daily carrying of heavy loads has been cited as an important risk factor associated with the frequency, severity, and resultant disability of low back pain and joint degeneration (Horal 1969). To avoid the possible hazards that are caused by stair descent, caution should be exercised in relation to the load carried, the frequency of the movement performed, and the use of shoes with proper cushioning ability.

The present study used the force-to-time ratio to assess the impulsive nature of the ground reaction force. Table 3 shows that there was no significant difference in the force-to-time ratio over loads. Averaged across loads, the force-to-time ratio for this stair mode (backpack 6567.0 N/s, athletic bag 6602.8 N/s) was about 3 times that for ascent (backpack 2241.4 N/s; athletic bag 2247.1 N/s) (Hong, Li, Mao 2004), which suggests that there is a much higher impulsive reaction in descent than in ascent. Previous research showed that the first peak force occurred at the loading response phase in descent, and that it was dominated by the absorption of energy at both the ankle and knee immediately after the leading leg landed (Zachazewski, Riley 1993). The high value of the force-to-time ratio in the present study further suggests that the physical action of walking down stairs results in higher dynamic loads on the children's musculoskeletal system than walking up stairs.

CONCLUSION: In stair descent, the first peak force was 1.59 times the second peak force. A load of 15% of body weight induced a significant increase in the maximum peak force (195% body weight) for both bags, which was 1.25 times that in the same stair mode with no load. The force-to-time ratio in stair descent was about 3 times that in stair ascent.

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